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Management systems may affect the feeding ecology of great tits *Parus major* nesting in vineyards

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Abstract

The current intensification of agriculture is leading to growing concern about the sustainability of modern farming systems, since farmland biodiversity has severely declined. While several studies have shown that vineyard management systems (i.e. organic vs. conventional) are important factors determining biodiversity and influencing population trends, there is a paucity of studies focusing on the effects at finer levels, such as breeding behaviour, habitat selection and movements. Here, we examined the effects of vineyard management systems on the breeding ecology of great tits (*Parus major*) in north-western Italy. We used nest-boxes to video-record feeding efforts of parents, and radio-telemetry to detect the movements of the males. Habitat composition between the two management systems differed. Organic vineyards were characterized by a high grass cover and the presence of fruit trees, while the presence of bare ground and the use of herbicides were typical for conventional vineyards. The number of nestlings fed by parents per visit and the weight of nine day old nestlings were significantly higher in organic than in conventional vineyards. The diet of nestlings was unaffected by the management system, but depended on the landscape characteristics. Caterpillars were the favourite prey in forest-dominated areas, whereas other invertebrates increased in vineyard-dominated areas. Feeding home range was also independent of the management system, but depended on the age of males (larger in adults). Habitat selection of feeding parents within home ranges was non-random in relation to habitat availability and changed according to the distance from the nest: parents selected forests when they moved far from the nest and used vineyards when remaining in the surroundings of the nest-box. Our results suggest that management systems may affect parental feeding ecology of great tits nesting in vineyards. Differences in the number of nestlings fed per visit and in the weight of the nestlings suggest that conventional vineyards offer fewer feeding resources (and/or of lower quality) than organic vineyards, with potential negative effects on survival of juveniles.

Keywords
Conventional and organic vineyards, video-recording, radio-tracking, home range, diet, landscape, habitat selection, great tit, Parus major

1. Introduction

The expansion of agricultural land is widely recognized as one of the most significant anthropic environmental changes. The overall surface of cultivated land worldwide increased by 466% from 1700 to 1980 (Meyer & Turner, 1992). While the rate of expansion has slowed over the past three decades, the yield (i.e. the amount of food produced per unit area of cultivated land) has increased dramatically (Naylor, 1996), which has also been supported by economic and technological incentives to increase productivity. Agroecosystems are sustained by diverse inputs, such as human labour and petrochemical energy and products, which replace and supplement the functioning of many ecosystems. The current intensification of agriculture is leading to growing concern about the sustainability of farming systems, since farmland biodiversity has declined severely (Kleijn et al., 2011; Vickery et al., 2004; Woodcock et al 2013). This is particularly important because modern agriculture has resulted in a loss of diversity (Aue et al. 2014) due to the homogenization in terms of crops grown and the increase of the yield per area on both animal (Donald et al., 2006; Vickery et al., 2004; Fuller et al., 2005; Mc Donald et al., 2012; Assandri et al., 2017) and plant diversity (Buhk et al., 2017).
There is evidence that 19 out of 46 farmland bird species significantly declined throughout Europe as a consequence of agricultural practices and intensification (Donald et al., 2006).
Organic farming systems are believed to have less environmental impact than conventional intensive agriculture, due to a reduced use of pesticides and inorganic nutrient application. Many studies have reported that organic farming increases biodiversity in the agricultural landscape, including, for example, carabid beetles (Caprio et al., 2015; Dritschilo & Wanner, 1980; Kromp, 1989; Pfiffner & Niggli, 1996;), vascular plants (Hyvönen & Salonen, 2002) and birds (Freemark & Kirk, 2001).
Italy houses about 10% of the surface of vineyards in the world (Organisation Internationale de la Vigne et du Vin OIV). The Italian region with largest surface of vineyards is Sicily with over 110’000 ha, followed by Apulia with 96000, Veneto, Tuscany, Emilia Romagna and

Piedmont. The percentage of organic vineyards in Italy is about 5.8% (Istat 2010). Several studies have shown that farming systems of vineyards are important factors determining biodiversity of plants and invertebrates (Bruggisser et al., 2010; Caprio et al., 2015; Costello and Daane, 2003; Di Giulio et al., 2001; Thomson and Hoffman, 2007; Trivellone at al., 2012;). For birds, most of the research has addressed the general effect of vineyard agroecosystems on communities (Assandri et al., 2016; Duarte et al., 2014) and populations. The hoopoe (*Upupa epops*), wryneck (*Jynx torquilla*), woodlark (*Lullula arborea*) and common redstart (*Phoenicurus phoenicurus*), for instance, are favoured by patches of bare ground (Arlettaz et al., 2012; Duarte et al., 2014; Schaub et al., 2010; Weisshaupt et al., 2011) within vineyards, indicating that a management that allows a patchy ground vegetation should be benefical for these species. However, there is paucity of research assessing the effects at finer levels, such as breeding behaviour, habitat selection and movements.

The great tit (*Parus major*) is a hole-nesting, insectivorous species whose contribution to pest control in apple orchards has been demonstrated (Mols & Visser, 2002, 2007). At the same time, orchard management may affect its survival and breeding success, reducing food resources and increasing intraspecific competition (Bouvier et al., 2005). In the present study, we examined the effects of vineyard farming systems (i.e. organic vs. conventional) on the feeding ecology of great tits nesting in vineyards of the Langhe and Monferrato wine-producing region, which has been recently marked as an UNESCO World Heritage Site. Here, regional applications of Common Agricultural Policies have promoted the placement of nest-boxes in vineyards to favor hole nesting insectivorous species, which can reduce insect damage and support local biodiversity. We used video-recordings at the nest to assess the number of nestlings fed per visit and their diet, whilst we used radio-telemetry to calculate feeding home range size and habitat selection of male parents.

2. Material and methods

2.1. Study area

The study was carried out in the Langa and Basso Monferrato Astigiano (NW Italy), a rural region where vineyards are the dominant cultivation, covering 34% of the territory. Other land uses include oak (*Quercus robur*), chestnut (*Castanea sativa*) and black locust (*Robinia pseudoacacia*) woodland (26%), arable land (19%), grassland and pasture (9%) and urban areas (3%). Viticulture in this area is very intensive, and the resulting landscape is dominated by large patches of monoculture, surrounded by forests, crops and grasslands. Vineyards in the study area are kept using the "*Spalliera*" trellising system. It is characterised by low vines (generally < 2 m) supported by wires held between wood or concrete poles. Hedgerows and isolated trees are often severely reduced. Organic vineyards are not abundant in the area and represent 1.86% of total vineyard area (246 ha of organic vineyards over a total cover of 16860 ha of vineyards in the study area). The climate of this region belongs to type Cfa (Temperate, without dry season, hot summer), in terms of Köppen-Geiger's classification (Peel et al., 2007).

We focused on 14 vineyard patches (focal vineyards) in 2011. Vineyard patches were all similar in size, ranging from 7.42 to 9.23 ha (average size: 8.10 ± 0.83 ha). Seven vineyards were certified for organic production, whereby no chemical treatments except sulphur, copper sulphate and pyrethrin sprays were used. The organic vineyard patches were in general adjacent to conventional vineyards and were isolated from other organic vineyards due to the reduced distribution of this kind of management. The other seven vineyards were cultivated with conventional production methods. These involved chemical treatments with pre- and post-emergence herbicides (mostly glufosinate), insecticides (mostly against flavescence dorèe), anti-rot compounds, sulphur, copper and zinc sprays, products with esaconazol and copper oxiclorur sulphate against oidium and rots, carbamate pesticides and fungicide, and the use of mineral feeds with average concentration of P, K and N at 6.5 q/ha.

2.2 Vineyard and surrounding landscape description

Focal vineyards were described in terms of habitat composition and management characteristics by means of percentage of grass cover, percentage of soil rubble cover, use of herbicides and/or ploughing (as a presence/absence variable), presence of trees (such as peach, pear and apple) and/or presence of rural building. Habitat differences between the two management systems (i.e. organic versus conventional) were explored using Factor Analysis (FA) (Riitters et al. 1995). We used land cover data digitized from 1:10000 aerial photographs to describe the landscape around the centroid of the focal vineyard patch both at a 500 m and a 1.5 km buffer radius. Seven local landscape variables were measured using a Geographical Information System (ESRI, 2006): the area of forests (FO), grasslands and pastures (PA), shrubs and bushes (BU), vineyards (VI), croplands and orchards (AG), garden patches (OT) and the aggregation index (AI). The AI quantifies the degree of fragmentation of a landscape and is calculated from a patch adjacency matrix, which shows the frequency with which different pairs of patch types appear side-by-side on the map (i.e. the buffer around the focal vineyard patch). Differences in land cover composition within the buffer around the focal vineyards regarding their management system (conventional or organic) were tested using a Kruskal-Wallis test due to non-normal distribution of the data.

2.3 Video-recording in nest-boxes

An artificial nest-box was installed as close as possible to the centroid of each vineyard (7 organic and 7 conventional). All nest-boxes were successfully occupied and were monitored by means of an infrared CCTV camera (Colour 420 line CCD high resolution camera) connected to a portable digital recorder (JXD990).

We recorded nest activity (for a minimum of 1 hour to a maximum of 3 hours per day) every two days during the morning, from egg hatching (day 0) for a total of 8-9 days recorded per nest. All recordings regarded the first clutch. Chicks were ringed and weighed at age 9 days. We recorded each parental visit to the nest-box, registering the sex of the parent and identifying the provisioned prey. Prey was classified as one of the following categories: butterfly's caterpillars (Lepidoptera), Spiders (Araneae) and other preys i.e. items that were brought less frequently, such as snails, or that were not identifiable based on the image analysis (i.e. other adult invertebrates and larvae). From the analysis of the videos, we estimated the time spent by the parents inside and outside the nest (in seconds). The average number of *pulli* fed per visit per nest was tested by means of a Generalized Linear Mixed Model (GLMM), using a Gaussian error distribution, treating nest identity as a random factor.

The effect of management system, landscape characteristics (i.e. the area of forests, grasslands and pastures, shrubs and bushes, vineyards, croplands and orchards, and garden patches) in a buffer of 500 m around the nest, the size of the vineyard and the percentage of prey categories identified in each nest was analysed by means of a GLMM with a Gaussian error distribution, treating nest identity as a random factor. Full models were subject to a model reduction procedure whereby non-significant terms were sequentially dropped from a model until only significant terms remained.

2.4 Radiotelemetry

Fourteen birds nesting in nest-boxes (seven in organic and seven in conventional vineyards) were fitted with transmitters. Tags were fitted to males only, to avoid between-sex variation and possible disturbance to incubating females. Individuals were captured using mist nets. One or two 12-m mist nets were placed at some distance from the nest (though along regular flight trajectories) to reduce disturbance.

Radio-tags were attached to the base of the central rectrice shafts using cyanoacetate glue and elasticized thread (Kenward, 2001). We used Biotrack PIP31 radio-tags (length 13 mm, width 5 mm, height 3 mm) with a weight of 0.35 g. Mean great tit weight was 18.7 g (± 1.7 se, range 18.0–20.0 g), hence tags were below the recommended 2% of body weight threshold for tail-mounted tags (Kenward, 2001); mean 1.87% (± 0.06 se, range 1.75–1.94%). Tail-mounted tags were lost during post-breeding moult.

Great tit radiotracking started the day after tag attachment and monitoring sessions were distributed equally over the daylight period. We used a Biotrack SIKA radiotracking receiver, with headphones and Yagi antenna. The position of the bird was assessed by triangulation and confirmed visually by two observers separated by 200-250 m from each other and from the nest-box. Observation points were used to allow the best possible view of the home range and to avoid signal loss due to the terrain. The tagged birds were monitored as intensively as possible, collecting the largest number of fixes possible for single individual (Aebischer et al., 1993; Naef-Danzer, 2000). Fixes were recorded every 10 minutes or every two consecutive visits in radiotracking sessions that lasted from 1 to 2.5 hours per day to reduce autocorrelation between fixes.

2.4.1 Home-range

Radio-tracking data were used to compute Kernel-based estimators, and we derived 95% and 50% Kernel Density Estimator (K95 and K50 respectively) (Gray et al., 2009; Holt et al., 2012) for all fourteen home ranges in ARCGIS 9.2, using Home Range Tool and Hawths Tools with a kernel smoothing by least squares cross validation. Only fixes of foraging birds were taken into account to describe home ranges. A mean of 77 fixes were obtained for each individual (± 4 se, range 58–110), which is above the 40 fixes recommended for unbiased estimates of home-range size (Seaman et al., 1999).

2.4.2 Compositional analysis

We considered used *vs* available land cover within the K95 and K50 home-ranges with the relative availability of the land cover around the centroid of the focal vineyards (i.e. a buffer of 500 m around each study site).

To evaluate hierarchical habitat preferences, we performed a compositional analysis (Aebischer et al., 1993; Holt et al., 2010) using the function "*compana*" in adehabitatHS package in R 3.2.3 (R core team 2015).

Land cover use values of zero were replaced with a number an order of magnitude smaller than the values for available and used land cover (Aebischer et al. 1993) and 1000 iterations were chosen for data randomization.

Habitat types were ranked independently of availability according to the number of positive differences between pairs of habitat types, with paired t-tests used to determine significant differences (Aebischer et al., 1993; Holt et al., 2010). Compositional analysis was performed separately for conventional and organic vineyards to evaluate differences in habitat ranks in the two different managements. Indices of land cover preference were calculated for the K95 and K50 of used land cover, by summing log ratios of differences between ranked land covers generated through compositional analysis.

3. Results

3.1 Vineyard and Landscape description

The habitat analysis showed that organic differed from conventional vineyards. Factor Analysis identified two axes that represented 87.61 % of the variance, with eigenvalues > 1. The first axis discriminated between conventional (associated with the use of herbicides and the percentage of soil cover) and organic vineyards (associated with the presence of fruit trees and high percentage grass cover values), while the second axis discriminated between sites with or without ploughing between vines (both conventional and organic vineyards could be ploughed) (Fig. 1).The analysis of the surrounding landscape showed that the variables (i.e. area of forests, grasslands and pastures, shrubs and bushes, vineyards, croplands, orchards, garden patches and AI) did not differ significantly between organic and conventional vineyards at the 500 m, nor at the 1.5 km radius scale (results not reported).

3.2 Video-recording in nest-boxes

We analyzed 220 hours of recordings from the 14 nests. Females spent more time inside the nest brooding the nestlings than males (GLMM: males -1.159 ± 0.202, DF 13, t-value: -5.733, $P < 0.001$), while males spent on average more time outside the nest looking for food than females (GLMM: males 0.105 ± 0.036, DF 13, t-value: 2.897, $P < 0.05$). There was no difference between organic and conventional vineyards regarding the time spent by parents inside or outside the nest-box. The number of nestlings fed per visit by parents was higher in organic than in conventional vineyards (GLMM: conventional vineyards: -0.122 ± 0.041, DF 12, t-value -2.985, $P < 0.05$) (Fig. 2). When parents fed more than one nestling, they bring small items (i.e. small spiders). The weight of the nestlings at age 9 days (when they were ringed by Enrico Caprio) was significantly higher in organic (average 11.99 ± 0.67 g) than in conventional vineyards (average 10.37 ± 0.63 g) (GLMM: conventional vineyards: -1.584 ± 0.360, DF 116, t-value -4.405, $P<0.001$) (Fig. 2). Neither the age of the males nor the clutch size influenced the weight of the nestlings.

We monitored 5427 feeding visits to nestlings and successfully identified prey in 55.96% of cases. On average, caterpillars represented 64.01 ± 19.99 %, spiders 6.41 ± 4.71% and other invertebrates 28.60 ± 16.46% of items brought by adults. The diet (expressed as percentages of the different items) was unaffected by the management system, but depended on the landscape characteristics around the nest and on the size of the vineyard patch. Caterpillars increased with increasing extent of forests, whereas the other invertebrates increased with the increasing extent of vineyards (table 1). No differences in nestling survival rates between organic and conventional vineyards were detected because all the nestlings successfully fledged and left their nest-boxes.

3.3 Home-range

On average, territory size was between 1 and 2 ha, whereas home range (K95) size varied from 5 to 24 ha (table 2). The average home range size of second calendar year great tit males born the year before capture (Euring age code 5) was significantly smaller than that of older individuals (Euring age code 6), independently of the estimator used (K95 or K50) (table 2). The size of home range was independent both of the management system (Kernel 95% $r = -0.22$, $n = 14$, $P = 0.412$; Kernel 50%: $r = -0.15$, $n = 14$, $P = 0.634$) and of the number of fixes (Kernel 95%: $r = 0.065$, $n = 14$, $P = 0.82$, Kernel 50%: $r = -0.178$, $n = 14$, $P = 0.42$).

3.4 Compositional analysis of home-ranges

Compositional analysis of home ranges showed that habitat selection of feeding parents was significantly non-random in relation to habitat availability (Table 3.). Forests were ranked higher than all other habitat types in K95 home ranges, while vineyards were ranked higher in K50 home ranges. There were no differences in the habitat ranking matrices when compositional analysis was performed separately for organic and conventional vineyards.

4. Discussion

To our knowledge, this is the first study on the feeding ecology of great tits nesting in vineyards under different management systems. By using video recording and radio-tracking techniques, we assessed the diet and weight of nestlings as well as the provisioning rate, ranging behavior and habitat selection of adults. Landscape variables did not differ significantly between organic and conventional vineyards at the 500 m nor at the 1.5 km radius scale. This suggests that the landscape surrounding conventional and organic vineyards was rather constant and that the selection of nest-boxes within vineyards was not dictated *a priori* by landscape differences. Conventional and organic vineyards differed at the vineyard scale. A high grass cover and the presence of fruit trees characterized organic vineyards, whereas the presence of bare ground and the use of herbicides characterized conventional vineyards.

4.1 Provisioning rate and nestling diet

Despite these differences at the vineyard scale, no differences in provisioning rates were detected, in keeping with previous data suggesting that habitat quality does not necessarily affect feeding rates in great tits (Wilkin et al., 2009). Feeding frequencies are often considered a poor indicator of the amount of food given to nestlings because the size of the prey may vary between feeds (Blondel et al., 1991, Nour et al. 1998). Moreover, higher feeding rates often correlate with smaller prey items, hence resulting in less food being delivered to nestlings (Naef-daenzer, 2000). In our study, more nestlings were fed per visit in organic than in conventional vineyards, and nestlings in organic vineyards were also significantly heavier at the age of nine days. This could indicate that parents were able to find better quality food and a higher abundance of preys and that increasing the number of nestlings fed per visit can be a way to optimize energy spent during feeding activity. During multiple feeding events we were not able to identify the preys, so small items were fed to nestlings. In all the references we have consulted great tits are considered single item feeders and it seems this is the first time this behavior is reported. Although it is possible that suboptimal habitat attracts poorly performing individuals, and that there may be a genetic trait beyond habitat selection and exploration abilities (Dingemanse et al. 2010, Carere et al. 2005) the discrepancies we mentioned above were not mirrored in different nestling survival rates, because, irrespective of the farming system, all the nestlings fledged and left the nest successfully. This confirms that parents are able to adjust their breeding strategies to different habitat conditions (Nour et al., 1998). However, the lower number of nestlings fed per visit and in the lower weight of the nestlings suggest that conventional vineyards offer fewer feeding resources and/or resources of lower quality than organic vineyards, with potential negative effects on survival of juveniles (i.e. post-fledging) (Naef-Danzer, Widmer & Nuber, 2001).

The diet of nestlings was unaffected by the management system, but depended on the landscape characteristics in terms of land cover. Caterpillars increased with forest extent whereas other invertebrates increased with vineyard extent, suggesting parents could find the best resources available in each habitat (in keeping with Wilkin et al. 2009). In local vineyards and adjacent forest patches, for instance, ground beetles and spiders are common and usually favoured by organic viticulture (Caprio et al., 2015).

4.2 Home ranges

Feeding home range was also independent of the farming system. Home range size ranged from five (for K50) to 10 ha (for K95). Home ranges of great tits breeding in oak-dominated broadleaf forests ranged from 0,33 to 0,42 ha (Naef-Daenzer, 2000), 0,24 to 0,37 ha (Naef-daenzer, 1994), 1.18 and 1.34 ha (Krebs 1971). Home range sizes of great tits nesting in vineyards were therefore very large, in keeping with the idea that great tits tend to occupy larger territories in habitats that are suboptimal in terms of resource availability (Krebs, 1971). Also Wilkin et al. (2009) suggested that a possible compensation strategy in response to a shortage of caterpillars may be to enlarge territories, although the responses could vary among individuals (Tremblay et al. 2005, van Overveld & Matthysen, 2010).

Compositional analyses of home ranges indicated that habitat selection of feeding parents was non-random in relation to habitat availability and changed according to the distance from the nest-boxes. Parents selected forests when they moved far from the nest and used vineyards when remaining in the surroundings of the nest-box, suggesting that even suboptimal vineyards can be a food source. Great tits in apple orchards have positive effects on pest control (Mols & Visser, 2002, 2007). Our data suggest that this species may also provide a similar ecological function in vineyards. Feeding home ranges depended on the age of males and were larger in adults (Euring age 6), possibly suggesting that more expert males know better the local allocation of feeding resources.

All in all, despite the relatively small sample size, our results are interesting as they show that the feeding ecology of great tits nesting in vineyards may be affected both by management systems and landscape characteristics. Organic farming systems should therefore take priority in agricultural policies, since they seem to host higher biodiversity (Bengston et al., 2005; Caprio et al., 2015; Hole et al., 2005) and preserve better quality food for great tits and seemingly also for other bird species. Concurrently, conservation of forest lots around the vineyards should be encouraged because they can provide better breeding and feeding opportunities. Heterogeneity of vineyard-dominated ecosystems (which implies the co-occurrence of vineyards and forest patches) may be the pivotal goal, because landscape heterogeneity along with vineyard management may also contribute to supporting a richer bird community (Duarte et al., 2014).

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*Table 1 GLMM of the effect of land cover in a buffer of 500 m around the centroid of the focal vineyard(%) on nestling diet. SD = Standard Deviation, DF = Degrees of freedom. *P < 0·05; **P < 0·01; ***P < 0·001; NS Not Significant.*

		Beta	SD	DF	t-value	P
Percentage of caterpillars						
	Intercept	0.35	0.1	12	5.533	***
	% of forest	0.53	0.1	12	5.03	***
Percentage of spiders						
	Intercept	0.11	0	12	5.31	***
	% of forest	-0.1	0	12	-2.64	*
Percentage of other invertebrates						
	Intercept	0.19	0.1	12	3.59	***
	% of vineyards	0.36	0.2	12	2.41	*

Table 2 Mean size (ha) of home ranges and territories of great tits according to the age of males.

Estimator	Age 6	Age 5	Kruskal-Wallis chi-squared	df	p-value
95% kernel	18.72 ± 8.40	8.46 ± 5.02	4.73	1	0.02
50% kernel	4.23 ± 2.12	1.76 ± 1.42	4.99	1	0.02

Table 3. Compositional analysis of used vs. available land cover according to different home-range estimators. FO: Forests, VI: Vineyards, GR: Grassland, OA: Other Agriculture, BU: Bushes, OT: Other

Estimator	Mean ± se	Range	Wilks Lamda	P	Habitat ranking
K95	11.34 ± 2.29	1.35 - 24.89	0.000003	***	FO VI AG BU GR OT
K50	2.64 ± 0.54	0.29 - 5.58	0.000151375	***	VI FO OT AG BU GR

Fig. 1 Factor analysis of grass cover, soil rubble cover, use of herbicides, ploughing, presence of trees (i.e. peach, peer, apple trees) and presence of rural buildings inside the vineyards between organic (full circles) and conventional (crossed squares) vineyards

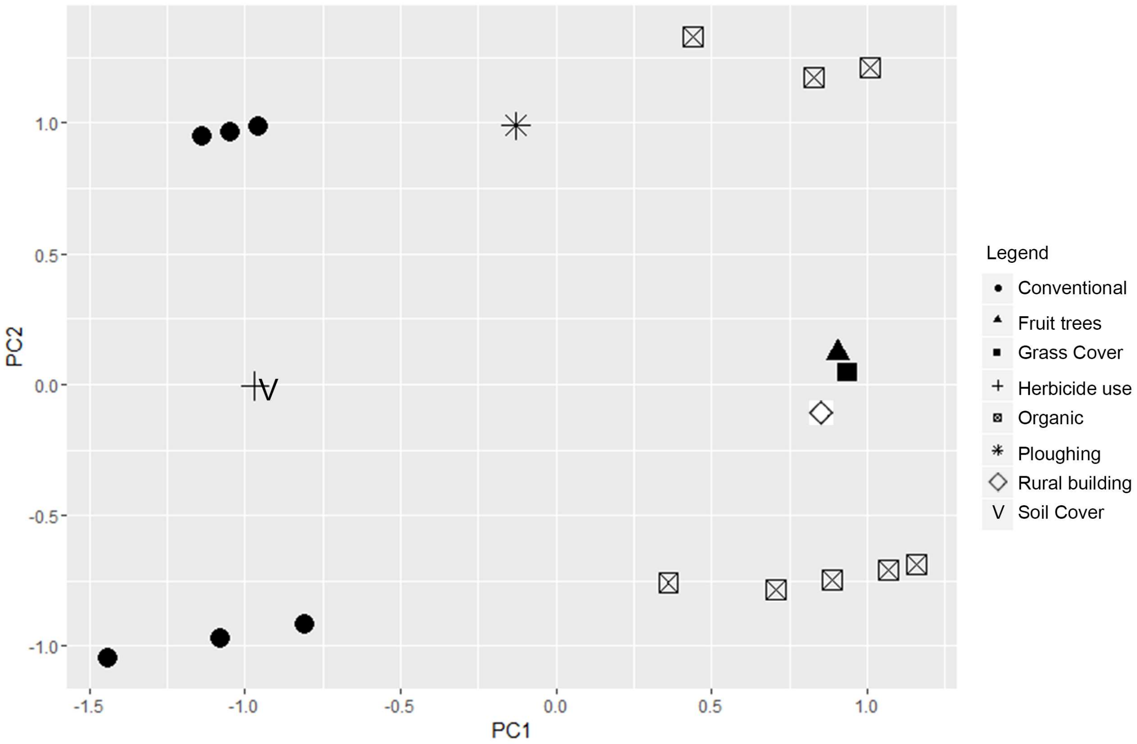

Fig 2. Boxplot of the average nestling weight (in grams) at age 9 days (top) and the average number of nestlings fed per visit by parents (bottom) in conventional and organic vineyards